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Deterministic Seismic Hazard Analysis For Shallow Earthquakes For Ballar Dam of Chhattisgarh State (India)

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Abstract— **Seismic vulnerability analysis, an approach to get an estimate of the strong ground-motions at any particular site, is mainly intended for earthquake resistant designs or for seismic safety assessments. The hazard study usually attempts to analyze two different kinds of anticipated ground motions, "The Probablistic Seismic Hazard Analysis" (PSHA) and "The Detemininstic Seismic Hazard Analysis" (DSHA). A sincere effort is made herein to do seismic hazard analysis for Ballar Dam of Chattisgarh state . An attempt was made to compile the occurrence of past and recent seismic activities within 300 km radius, around the Dam site. Further the seismic hazard analysis was carried out at substratum level in terms of PGA using (DSHA), deterministic seismic hazard analysis technique The main benchmark and indicator involved in carrying out the hazard analysis is the correctness and completeness of the data which needs to be attained. The knowledge presented in this paper helps in evaluating the seismicity of the region around, Ballar Dam Site after statistical analysis of the database. Finally the results are furnished in the form of peak ground acceleration (PGA) for 50 Percentile & 84 Percentile with 100 years of Recurrence Period which can be used directly by engineers as fundamental considerations, for generating earthquake-resistant design of structures in and around Ballar Dam.**

Index Terms— **Seismic hazard; Ballar Dam; DSHA; Fault Map; Recurrence Period; PGA.**

I. INTRODUCTION

In the recent years, the attention of the scientific community regarding seismology and seismotectonic study has enhanced significantly in Peninsular India (PI), especially in the field related to seismic hazard assessment, of seismic areas and its possible reduction measures. The hazard in this part of India is considered to be less critical than in the Himalayan plate boundary region. The fact that the Earthquakes in various parts of India as compared to the Himalayan Plates are less severe, is totally based on the relative occurrence of past tremors in the various regions. However, intra-plate earthquakes are rarer than plate boundary events but usually tend to be more harmful. Paucity of recorded ground motion data introduces uncertainties in predicting the nature of occurrence of future ground motions and the dynamic forces, which needs to be considered in the designing of manmade structures. The behavior of a building, dam or a power plant depends primarily on the local ground motion at the foundation level. A fairly accurate knowledge of such motions, pertaining to all possible sources in the influenced zone of about 300 km radius around the construction site, is the most sought information in engineering practices. The existing Indian code IS-1893 does not furnish any quantification of seismic hazard. Seismic hazard analysis plays an important role in generating earthquake-resistant design of structures by providing a rational value of input hazard parameters, like peak ground acceleration (PGA). Traditionally, PGA has been a popular hazard parameter, but it is often found to be poorly correlated with the damage potential of ground motion. All the existing researches, related to seismicity in India, have been made simply in terms of the peak ground acceleration or by using the attenuation relations for some or the other parts of the world.

Table 1.Salient Features of Dam Site

Name of the Dam	Ballar Dam
Basin Name	Mahanadi
River	Balar Nalla
Dam Type	Earthen
Purpose	Irrigation
Length of Dam (m)	945.12
Dam Height (m)	19.7
Design flood (cumec)	603.5
Crest Level of spillway	314.58
Spillway capacity (cumec)	606.64
Seismic Zone	Seismic Zone-II

II. SEISMICITY OF THE REGION

The present study uses a Deterministic method for the Hazard Analysis of Ballar Dam taking into consideration the location of Chhattisgarh, it is found to be located in the zone where the occurrence of seismic activity is found to be very low. In recent past, tremors from earthquakes have been felt, in neighbouring states, most notably in 1969 not forgetting

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minor seismic activities that have been recorded in the vicinity of Chiraikund and Muirpur along the border of Madhya Pradesh. Many faults have been identified further, for eg. few faults form the eastern section of the Narmada-Son Fault Zone which have shown movements during the Holocene epoch. Another active fault identified is the Tatapani Fault which trends in an east-west direction in the vicinity of Manpura in Sarguja district. In the southern part, the Godavari fault, flanking the northern part of the Godavari Graben run, through the southern part of the state and is also found to be active. The known earthquakes in this region had either observed intensities of V or higher (historical events) or had known magnitudes of M 4.5 or more (instrumented events).

III. Identification and Characterization of Sources

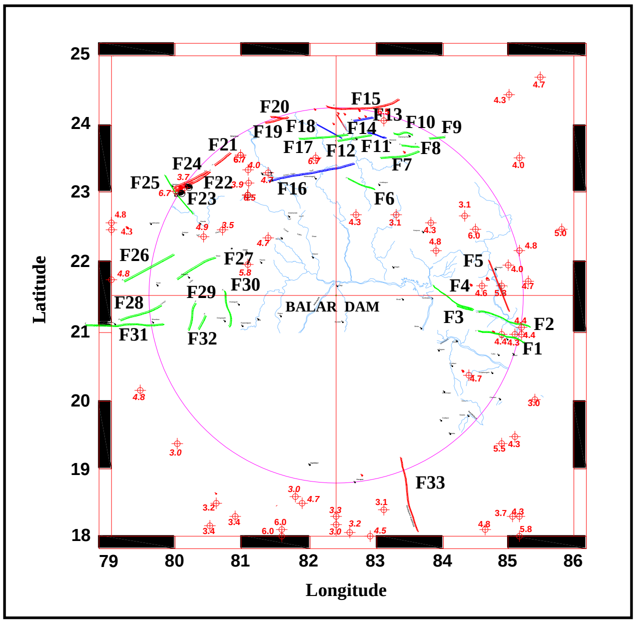

Figure 1: Seismotectonic map of Ballar Dam

Now coming back to the present study after a general introduction to the state, because Ballar Dam is selected as the target, including a control region of radius 300 km around the District Headquarter, having centre at 21° 32' N, 82° 30' E, was considered for further investigation. The fault map of this circular region which was prepared in reference with the Seismo-tectonic Atlas of India, is as shown in Figure 3.1. From Figure 1, it is obvious that in recent years seismic activity appears to be concentrated along Bamhni-Chilpa fault (F16-140 km in Length) and Parvatipuram- Bobbili Fault (F33-121 km in Length) . A total of thirty-three major faults, which influence seismic hazard at Ballar Dam , were identified in the above map. Fault details are tabulated in Table 2.

Table 2. Faults Considered for Hazard Analysis around the Ballar Dam

Fault no.	Length in km	Hypo. Distance	Weightage	Moment Magnitude (M_W)
F1	75	235.57	0.0379	4.9
F2	86	230.66	0.0435	4.9
F3	26	195.33	0.0132	5.1
F4	75	157.56	0.0379	5.1
F5	87	251.85	0.044	5.8
F6	46	180.55	0.0233	4.8
F7	62	230.78	0.0314	7.0
F8	28	261.62	0.0142	7.0
F9	25	292.00	0.0127	7.0
F10	30	274.73	0.0152	7.0
F11	30	264.39	0.0152	7.0
F12	55	246.40	0.0278	7.0
F13	32	279.98	0.0162	7.0
F14	30	263.55	0.0152	7.0
F15	117	302.45	0.0592	7.0
F16	140	211.60	0.0708	7.2
F17	78	256.85	0.0395	7.2
F18	45	251.60	0.0228	7.2
F19	28	295.17	0.0142	7.2
F20	28	294.59	0.0142	7.2
F21	33	282.80	0.0167	7.2
F22	51	281.30	0.0258	7.2
F23	31	292.77	0.0157	7.2
F24	60	285.30	0.0304	7.2
F25	76	263.55	0.0385	7.2
F26	91	267.44	0.046	5.3
F27	70	202.00	0.0354	6.3
F28	70	280.35	0.0354	6.3
F29	45	225.09	0.0228	6.3
F30	58	178.93	0.0294	6.3
F31	125	280.08	0.0632	6.3
F32	25	211.15	0.0127	6.3
F33	121	280.34	0.0612	3.6

After going through various available literatures and sources such as (USGS, NIC), 78 Nos. of Earthquakes in the magnitude range 3< Mw <6.7 for Ballar Dam, occurring over the period from 1837 to 2012 were identified in the present study. In places where the magnitude of any event was not available in the previous reports, they were derived using the approximate empirical relation [m = (2/3) I0 + 1] using the reported maximum MMI number. To avoid further confusion associated with different magnitude scales, all magnitudes were converted to moment magnitude M_w. Based on the nearness of epicenters to a particular fault, the maximum potential magnitude mu of each fault was fixed, which were kept 0.5 units higher than the magnitude reported in the past as observed from Figure 1 and value of moment magnitude M_w is given in Table 2.

IV. Regional Recurrence

Seismic activity of a region, is usually characterized in terms of the Gutenberg–Richter frequency–magnitude recurrence relationship

$$\log10 (N) = a - b*M_w$$

where N stands for the number of earthquakes greater than or equal to a particular magnitude M_w. Parameters (a, b) characterize the seismicity of the region. The simplest way to obtain (a, b) is through least square regression, but due to the incompleteness of the database, such an approach may lead to erroneous results. Kijko and Sellevoll have proposed a reliable statistical method to address the issue of incompleteness of earthquake catalogues. They classified the database into two groups, called the extreme part and the complete part. The extreme part consists of a long time period where information related to only large historical events is consistently available. The complete part further represents the data related to the recent decades during which information on both large and small magnitude earthquakes is available. As it is very clear that, in hazard analysis one would not be interested in events below a threshold level, say $m_0 = 3$. Again, there will be an upper limit on the potential of a fault, but it may be difficult to know the actual precision of the faults from the catalogues, thus the above stated method, suited to engineering requirements, which can easily estimate such doubly truncated Gutenberg–Richter relationship with statistical errors in values of the magnitude that have occurred in the past. The present study, incorporates the earthquake data of the samples, of past 176 years around Ballar Dam , was first evaluated for its degree of completeness.

Table 2. Activity Rate and Completeness for Ballar Dam

The analysis is shown in (Table 2), that data are complete, in a statistical sense, in the following fashion: ($3.0 \leq Mw < 4$) is complete in 40 years; ($4.0 \leq Mw < 5$) is complete in 70 years;

($5.0 \leq Mw < 6$) is complete in 100 years; and ($6.0 \leq Mw < 7$) is

Magnitude Mw	No. of Events ≥ Mw	Complete in interval (year)	No. of Events per year ≥ Mw
3.0	78	40	1.950
4.0	55	70	0.785
5.0	20	100	0.200
6.0	8	130	0.061

complete in 130 years. Regional Recurrence Relationship Ballar Dam is given by

$$\text{Ballar Dam Log 10 (N)} = 3.5624 - 0.6252M_w$$

Norm of residuals R2= 0.51387

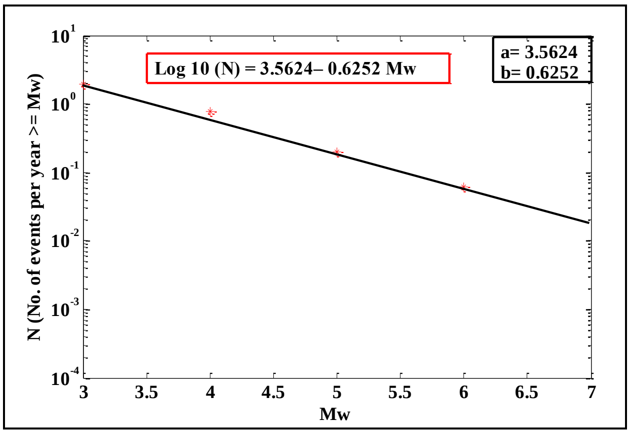

Figure 4.30: Regional Recurrence Relationship at Ballar Dam

V. Ground Motion Attenuation

Attenuation relationship developed by Iyenger and Raghukanth (2004) was considered for the analysis and PGA was calculated. Maximum value of PGA has been taken amongst the PGA calculated by various source at each point.

$$\ln (PGA/g) = C1+C2 (M-6)+C3 (M-6) 2-\ln(R)-C4(R) +\ln \varepsilon$$

Where, C1= 1.6858, C2= 0.9241, C3= 0.0760,

C4= 0.0057, R= Hypo central distance, M= magnitude = M100, ln ε = 0 (for DSHA) for 50 Percentile, ε = 0.4648 for Percentile

VI. Deterministic Estimation of PGA

Finally the Deterministic Seismic Hazard Analysis (DHSA) was carried out for Ballar Dam considering the seismic events and Seismotectonic sources from the newly developed seismotectonic model for the region, 300 km around the District Headquarter. The maximum possible earthquake magnitude for each of the seismic sources within the area was then estimated.

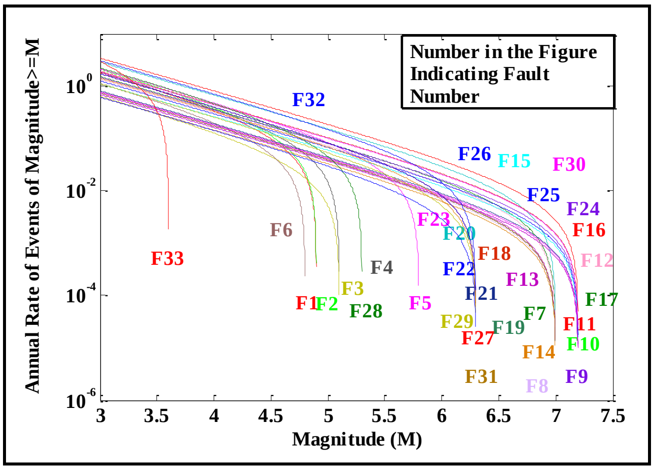

Figure 4.3: Deaggregation of Seismic Sources Near Ballar Dam

Shortest distance to each source and site of interest was evaluated and taken as major input for performing DHSA. In the present investigation truncated exponential recurrence

model developed by Mcguire and Arabasz (1990) was used and is given by following expression;

$$\lambda_m = (m_0) * \upsilon * \frac{\exp[-\beta(m-m_0)] - \exp[-\beta(m_{max}-m_0)]}{1-\exp[-\beta(m_{max}-m_0)]}$$

Where $\upsilon=\exp(\alpha-\beta*m0)$, $\alpha=2.303*a$, $\beta=2.303*b$ and Ni(m0) is the weightage factor for a particular source based on recurrence. The threshold value having a magnitude 3.0, was adopted in the study.

Table 3:PGA For M_{100} Earthquakes at Ballar Dam

Fault No.	Fault Length	Hypo Central Distance R in Km	Magnitude M_{100} [100 years Recurrence Period]	PGA Values (g) (100Years)	
				50 Percentile	84 Percentile
F1	75	235.575	4.849	0.00187	0.00297
F2	86	230.667	4.853	0.00197	0.00314
F3	26	195.337	4.915	0.00304	0.00485
F4	75	157.568	5.621	0.00972	0.01547
F5	87	251.851	5.64	0.00362	0.00576
F6	46	180.551	4.728	0.00292	0.00464
F7	62	230.787	6.228	0.00772	0.01228
F8	28	261.622	5.804	0.00386	0.00615
F9	25	292.004	5.74	0.00274	0.00436
F10	30	274.73	5.846	0.00355	0.00565
F11	30	264.393	5.831	0.00386	0.00614
F12	55	246.405	6.176	0.00631	0.01005
F13	32	279.986	5.876	0.00348	0.00554
F14	30	263.555	5.848	0.00395	0.00629
F15	117	302.458	6.504	0.00497	0.00792
F16	140	211.608	4.846	0.00238	0.00378
F17	78	256.851	6.402	0.00696	0.01108
F18	45	251.607	6.133	0.00577	0.00919
F19	28	295.177	5.843	0.00293	0.00467
F20	28	294.59	5.848	0.00296	0.00472
F21	33	282.802	5.923	0.00354	0.00564
F22	51	281.302	6.179	0.00454	0.00723
F23	31	292.773	5.89	0.00314	0.00499
F24	60	285.306	6.272	0.00476	0.00757
F25	76	263.555	6.377	0.00639	0.01017
F26	91	267.441	5.222	0.00204	0.00325
F27	70	202.002	5.954	0.00809	0.01288
F28	70	280.353	5.954	0.00373	0.00594
F29	45	225.095	5.821	0.00562	0.00894
F30	58	178.932	5.894	0.00985	0.01568
F31	125	280.081	6.076	0.00419	0.00666
F32	25	211.159	5.577	0.00512	0.00815
F33	121	280.346	3.597	0.00027	0.00043

VII. RESULT AND DISCUSSION

The present research, the seismic hazard analysis carried out, for the establishment of PGA at substratum level for Ballar Dam, was based on deterministic approach. An attempt has also been made to evaluate the seismic hazard in terms of PGA at the same level. The Regional Recurrence Relationship obtained for Ballar Dam as depicted in Equation 1 shows the obtained "b" value as 0.6252. The Values of P.G.A. for M_{100} Earthquakes have been shown in Table No.3. The Maximum value of Peak Ground Acceleration (P.G.A.) for recurrence period of 100 years for Ballar Dam was found to be due to the fault No. 30 (Fault length 58 km, Min. Map Distance 178.932 km) which came out to be equal to 0.00985g for 50 Percentile and 0.01568g for 84 Percentile. The study results outlined in this paper can be directly be implemented for designing of earthquake-resistant structures, in and around Ballar Dam.

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